CENTRE NATIONAL D'ÉTUDES SPATIALES

HYPERTROPIK PROJECT FOR HYPXIM MISSION

Mapping tropical biodiversity using spectroscopic imagery : characterization of structural and chemical diversity using 3-D radiative transfer modeling

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HYPXIM MISSION: BRIEF HISTORY & CURRENT STATUS

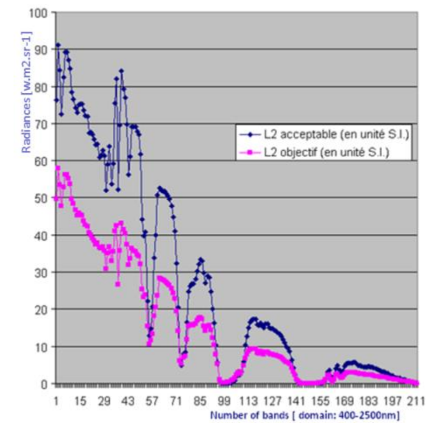
- **HYPXIM is a Civil and Defense (ie dual) High Resolution (8m) hyperspectral mission funded by CNES (French Space Agency). Phase 0 begun in 2009. Phase A was decided in July 2012**

    - A national dual group (GSH) collegially addressed clear and very detailed needs for a high resolution hyperspectral mission in 6 major themes: vegetation, coastal and inland water ecosystems, geosciences, urban environment, atmospheric studies, security and defence.
    - This needs conducted to a mission requirements in terms of spectral domain, spectral resolution, signal-to-noise ratio, spatial resolution, swath and revisit period, which revealed as the main drivers for the design of a hyperspectral space instrument.
    - Two satellite systems architectures were preliminary designed to meet these requirements, with industrial support from Airbus Defence and Space (ADS) and Thales Alenia Space (TAS)
      (see next slide)

Domain	Spectrum (nm)	Spectral res. $\delta\lambda$ (nm)	SNR
VIS	400-700	10	$\geq$ 250:1
VNIR	700-1100	10	$\geq$ 200:1
SWIR	1100-2500	10	$\geq$ 100:1
PAN	400-800	400	$\geq$ 90:1

GSR: 8m

1,8 m



- **The phase A has been frozen in early 2013 for financial reasons, until conclusions of the Scientific Propective Seminar of CNES (SPS) hold in March 2014.**

- **SPS planned this mission at "middle term horizon (2023-2025)" and recommended the reorientation of scientific activities in priority around the consolidation of requirements for 3 themes: <u>Littoral ecosystems</u>, <u>Urban applications</u> and <u>Tropical Forest Biodiversity</u>.**

HYPXIM MISSION: MICROSAT vs MINISAT

With the same instrument design two levels of GSR performances depending on the size of the telescope and orbit

Pupil Φ 150 mm /15m pixel resolution @ 650km or 8m resolution @350 km (under study)

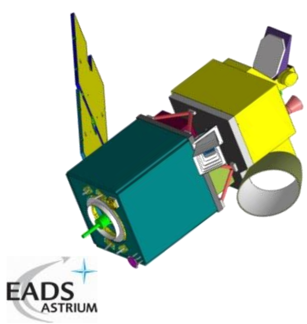
↓

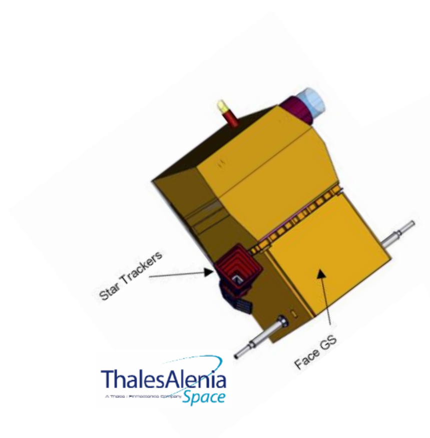
On Microsat: 200 kg range

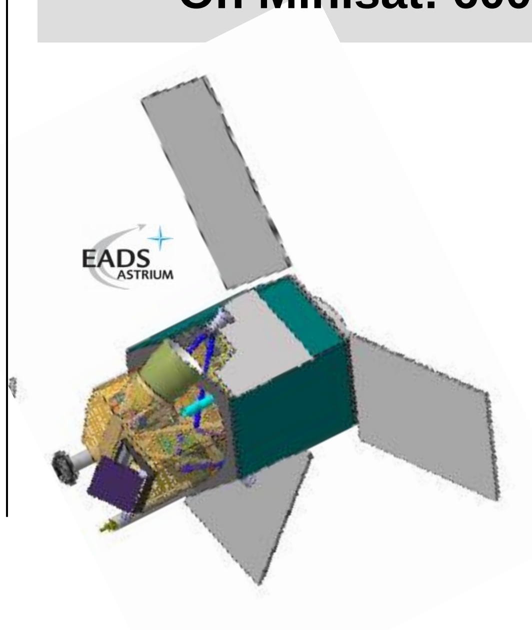
Pupil Φ 450 mm / 8m resolution

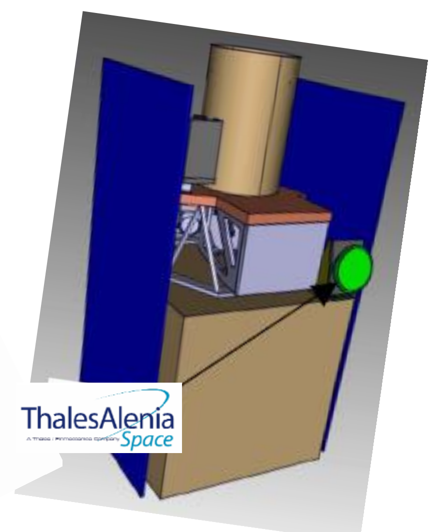
↓

On Minisat: 600 kg range





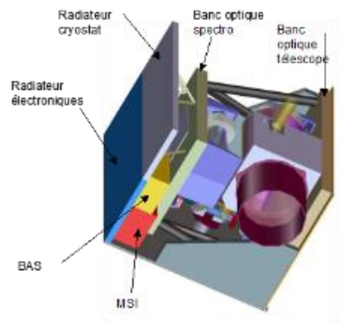


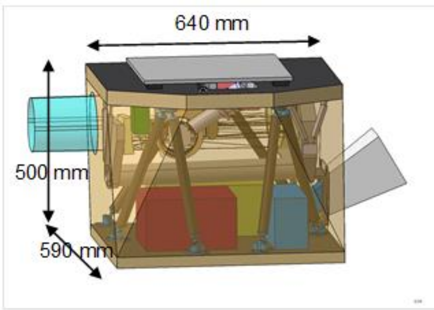


HYPXIM MISSION: MAIN CHARACTERISTICS

Altitude	660 km
Payload	TMA or Korsch telescope Φ450 mm, Detector HgCdTe 2000 x 360 pixels
Resolution/Swath	8 m / 16 km
Spectral bandwidth	400 – 2500 nm / 10 nm
Panchromatic band	Resolution: 1.85m
Payload budget	Mass ~115 kg, Power < 150 W (imaging)
Satellite	600 kg (at launch)
Revisit period (+/-60° in latitude)	+/-20° across-track imaging : 15 days +/-35° across-track imaging : 3 days (with 1 satellite)
Imaging capacity (for one satellite)	~100 000 km2 per day (270-450 images)
Link to Ground	X-band link at 620 Mbps (with ground or mobile stations)
Launcher compatib.	Soyuz, Vega, Ariane 5
Expected lifetime	10 years (incl. end-of-life operations)

Lefèvre et al. (2012), ISPRS Congress , Melbourne

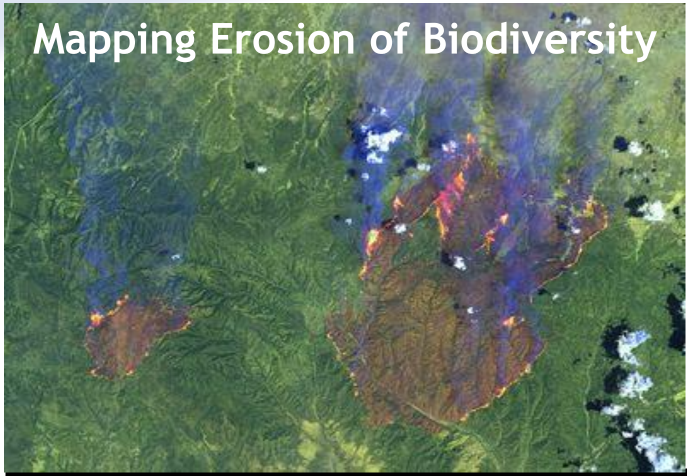




MATURATION OF INSTRUMENTAL REQUIREMENTS:

Need to improve physical interpretation of the signal reflected by complex targets, in particular in tropical forests for biodiversity mapping -Link with Lidar is also under study .

TROPICAL FOREST BIODIVERSITY STUDY: A GLOBAL INTEREST



Jesse Allen, data courtesy Landsat 7 Science Team,

Human activity (urbanization, deforestation, farming / agriculture, exploitation of geological resources) and climate change, globally affect ecosystems, causing accelerated erosion of biodiversity.

Tropical ecosystems are particularly affected by anthropogenic pressure. These regions host the most global biodiversity ('hot spots').

France is the home of 40% of the European flora (because numerous territories located in tropical region) and has a special interest for forest biodiversity research. But knowledge of these forests (species distribution, role in the carbon balance of the planet) is extremely low .

Improved characterization of tropical biodiversity is a priority for forthcoming spatial missions programmed for the next decade, such as **HYPXIM**.

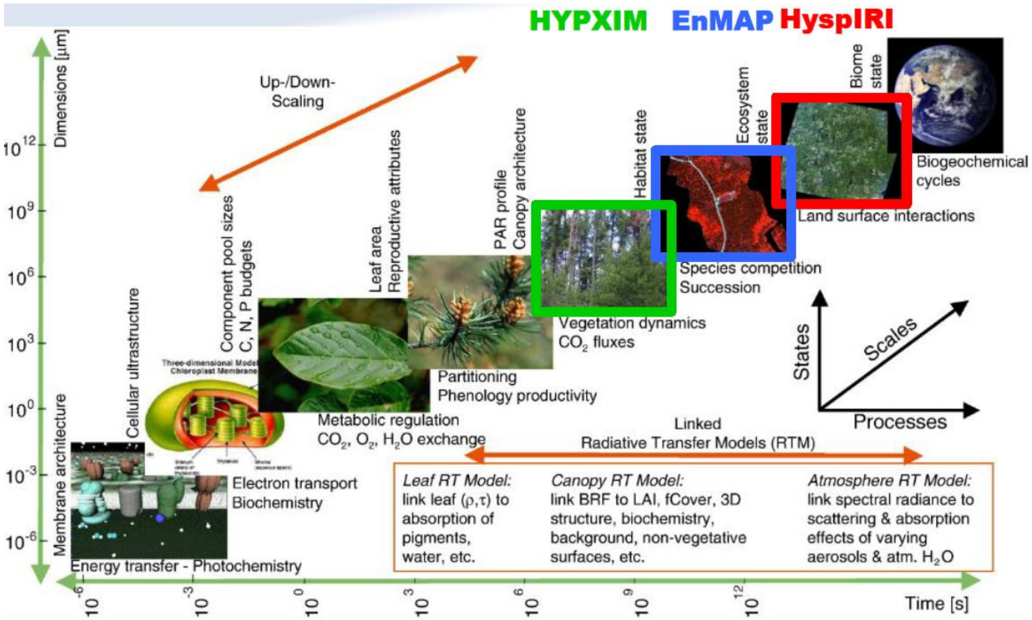
HYPXIM: MULTISCALE CAPABILITIES FOR TROPICAL FORECT BIODIVERSITY STUDIES

HYPXIM Mission (Lefevre Fonollosa et al., 2012) aims to provide information about the characteristics of the vegetation from local scale (crowns) to regional scale (species communities across landscapes).

HYPXIM will provide estimates of vegetation properties with sufficient precision to force the model variables or data assimilation procedures.

In some good atm. conditions, HYPXIM will provide temporal series of these estimations with a spatial scale compatible with models and field observations.

Properly used, these data will facilitate the transfer from local observations of vegetation properties to the regional or global scales to meet the needs of ecologists and Biosphere models.

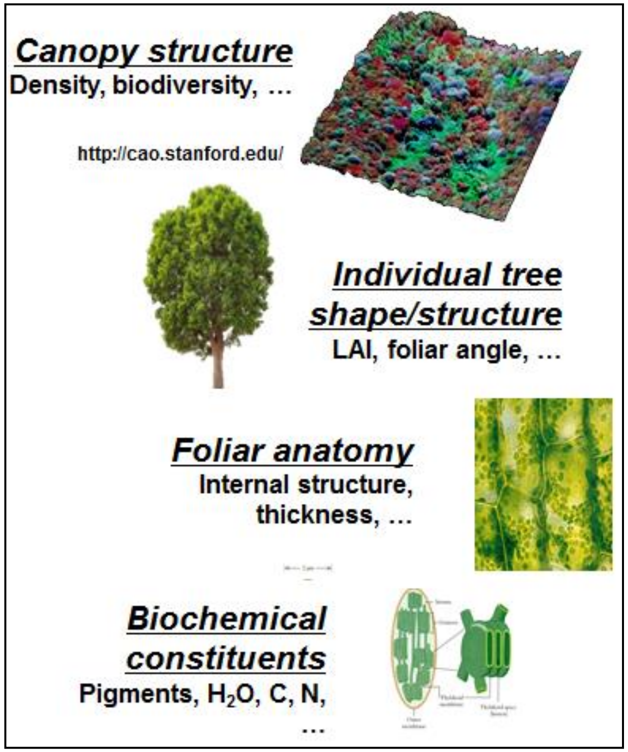


TROPICAL FOREST BIODIVERSITY: A CHALLENGE FOR HYPXIM (1/3)

In tropical forests, ecological processes heavily depend on the structure of the canopy (size, shape, dominance of trees) and also the ability of each species to capture light and nutrients in the soil.

Airborne HR imaging spectroscopy has demonstrated its potential in tropical environments:

- Confirmation that trees structure combined with leaf biochemical properties influence the radiometric signal reflected by vegetation and contribute to the estimation of biodiversity (Carlson et al., 2007)
- Identification of tree species (Clark et al, 2005; Féret & Asner 2013)
- Mapping at fine scales as well local species diversity (α-diversity), than changes in forest species communities (β-diversity) (Féret & Asner 2014).



But what <u>performance and limits for spaceborne system</u> ? We need to consolidate HYPXIM specifications for this topic.

TROPICAL FOREST BIODIVERSITY: A CHALLENGE FOR HYPXIM (2/3)

Because of **complexity and low level of luminance** on tropical forest landscape, the consolidation of HYPXIM mission requires a better understanding of the physical signal.

It is also necessary to better understand the relative influence of all biological and structural factors in the measured signal (with sensibility studies).

But use of experimental data **is technically, financially and logistically limited** for such tasks, and does not allow accurate and frequent physical measurements.

Approaches using radiative transfer modeling can improve physical interpretation of the radiometric signal interacting with the surface and acquired by the spaceborne sensor.

TROPICAL FOREST BIODIVERSITY: A CHALLENGE FOR HYPXIM (3/3)

In synthesis:

- Heterogeneity and complexity of forest structures
- Species diversity at all scales of observation
- Variability of forest functioning patterns
- Extents of forest biomes

=> Classical approaches **are not sufficient.**

Our solution is based on: **DART** radiative transfer model for 3D complex forest structure and **PROSPECT** for leaf biochemical composition.

DART: Remote Sensing (images VIS → IRT, Lidar) and 3D radiative budget of natural and urban landscapes

HYPERTROPIK PROJECT

[Selected by CNES Science TOSCA Programme, 2014, for 3 years]

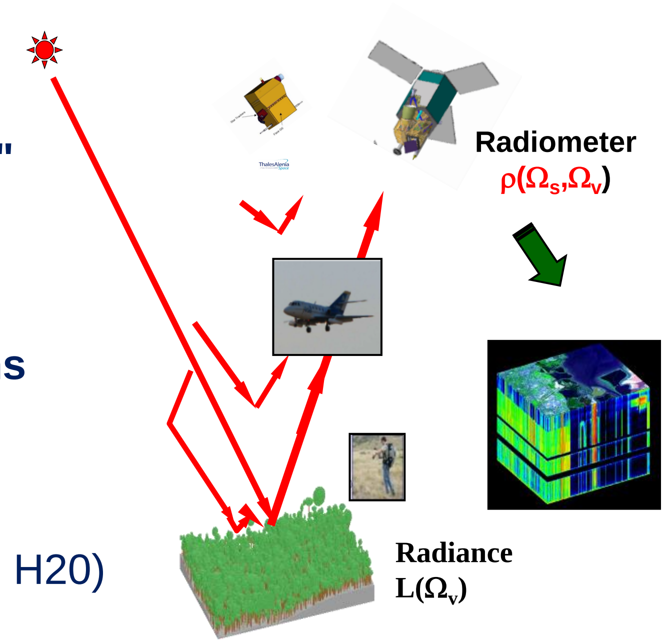
The goal of the project is double:

- to work from *in situ* measurement to satellite simulations through DART model and airborne data

- to deliver validated hyperspectral products for Forest Biodiversity and consolidate HYPXIM specifications within the coming 3 years.

HYPERTROPIK PROJECT SUMMARY

The project is structured into 4 steps:



- **First step (2014-2016)**, develop a simulator "**end to end"** based on DART for an improved understanding of the hyperspectral signal at different scales

- **Then (2015-2016)** develop, adapt and validate **algorithms** focusing on vegetation parameters such as:
  - biological and structural diversity mapping,
  - quantification of biophysical parameters (LAI)
  - Quantification of biochemical parameters (pigments, H20)

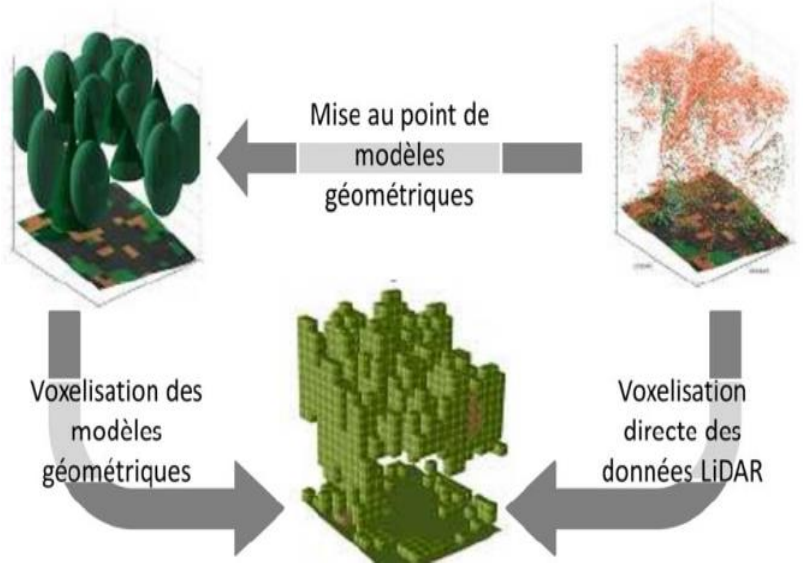
- **Airborne Hyper and Lidar acquisitions (2015-2016)**, for validation of DART, and parametric studies at various conditions of acquisition (sun/view angle, atmospheric disturbance,...)

- **Parametric studies** based **on DART+ Airborne simulations (2016-2017)** for various conditions of acquisition (sun/view angle, atmospheric disturbance,...) and a range of spatial, spectral, and radiometric resolution, to establish a set of well-argued HYPXIM Mission requirements

« END TO END » PHYSICAL MODELING & VALIDATION (1/2)

The objective is to produce realistic simulations from a selection of test sites. Test site models will be validated by airborne/satellite measurements

1- Geometric Mock-Up:
Two approaches are implemented with DART:
a) a direct model, by voxelization of accurate 3D representation (e.g. *in situ* T-LiDAR point clouds);
b) an indirect modeling, using a simplified geometric models which is applied before the voxelization (it can be parameterized from LiDAR measurements).
Schneider et al. (2014) obtained better results with the direct approach.



2- Radiometric information:
Field data collect at various levels of detail, from a simple description (landscape, plot and tree), to all vegetation properties (chemical and geometrical), and the conditions of observation which interact with the signal measured by a spatial sensor.
This biological panel of observations are completed by some physical data: in situ reflectance, leaf optical properties (vertical and horizontal variability, intra- and interspecific) and other components of the landscape (soil, litter, trunk and branches).
These field information are analyzed and archived.

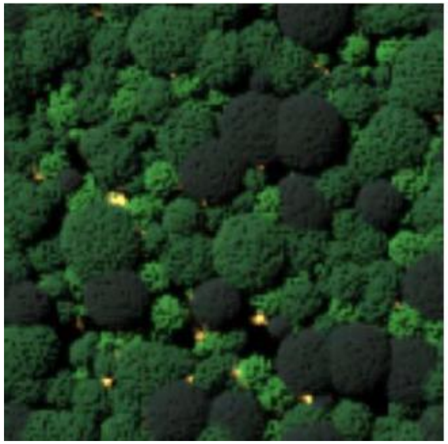
« END TO END » PHYSICAL MODELING & VALIDATION (2/2)

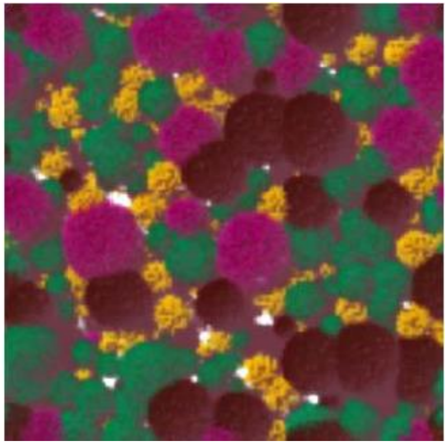
3- DART model step: from a 3D Radiative transfer model to simulated hyperspectral images:
DART is based on the 3D representation of various components of the scene (mock-up, atmosphere, MNT, solar direction) and instrumental characteristics (spectral domain, spatial resolution, view direction, ...).
The vegetation can be simulated as a medium constituted by the juxtaposition of turbid cells (LAI, LAD, ...) and / or as a collection of triangles with translucent optical properties and specific orientations, etc.
DART generate hyperspectral images of radiance and realistic HYPXIM simulations

4- Airborne validation Campaign :
Critical for the validation of DART simulations and preparation for HYPXIM acquisitions.

The aim is to compare the images of radiance generated by DART with airborne/satellite hyperspectral images.

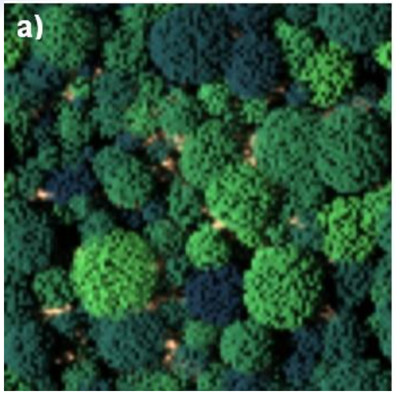
This data will be also used for a parametric study focusing on instrument requirements and conditions of acquisition.

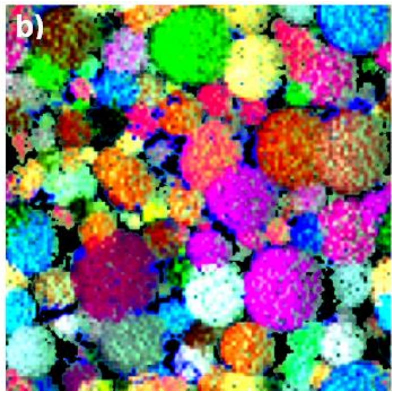




ALGORITHM STUDIES: PRELIMINARY RESULTS (1/3)

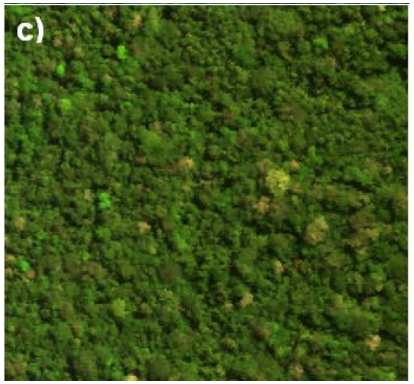
Quantification of biophysical parameters (LAI) and biochemical (pigments, …)

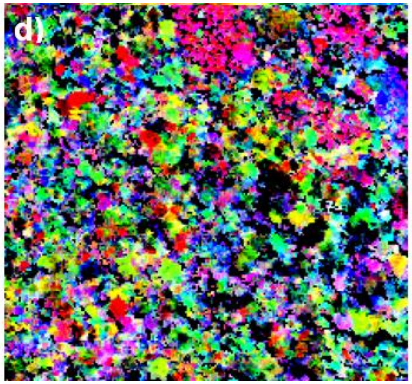




DART simulations have been developed, integrating a variety of 20 distinct leaf optical properties distributed between the trees @ 50cm resolution.
Fig a): RGB presentation of an hyperspectral simulation
Fig b): combination of 3 components from the PCA, highlighting these leaf optical properties

Comparison of this approach using an hyperspectral image acquired by the Carnegie Airborne Observatory (CAO) (Site: CICRA, Peru; Féret & Asner, 2014).
Despite the lower spatial resolution (2m), a similar PCA processing allows extraction of signal components corresponding to characteristics of individual trees/species, partly explained by variations in leaf optical properties.





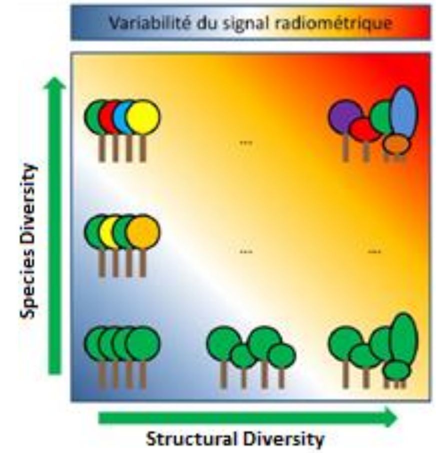
=> A quantitative comparison shows a greater variability in the simulations DART vs CAO data. In tropical environments, photosynthetic pigment content is generally very high, close to saturation in the visible domain and reduce the variability of the signal. So, the excessive variability in the DART simulation is due to under-estimated pigment content.

ALGORITHM STUDIES: PRELIMINARY RESULTS (2/3)

For mapping biodiversity, how to distinguish the biochemical composition from the structural complexity ?

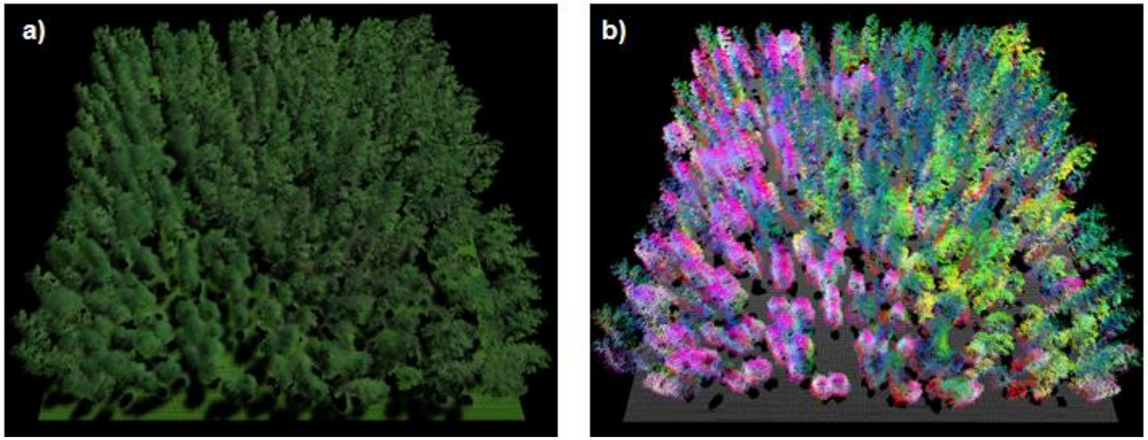
Spectral information allows accurate identification of tree species based on their chemical composition and their structure.

Spatial analysis based on size attributes, shape and texture, which also help describe the canopy, (for example: development stage for mangroves)



Our aim:

- to separate the signal of vegetation from other types of surfaces,
- to identify the tree species through their "specific spectral signature"
- to detect signals related to environmental factors or vegetation phenology inducing changes in the foliar optical properties

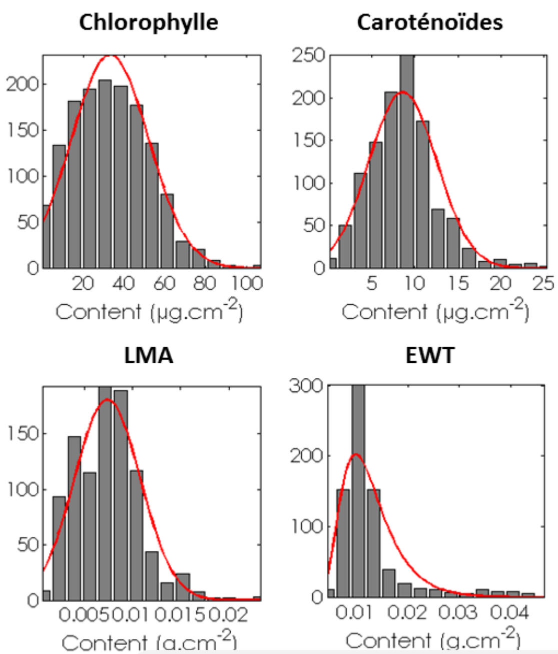


Example of Järvselja birch stand (Estonia):
(a) RGB 3D representation of a combination of Lidar and hyperspectral simulation by DART (RAMI-benchmark, JRC);

(b)Three components selected from a PCA hyperspectral DART simulation, highlighting species variability in function of their structure and foliar chemistry.

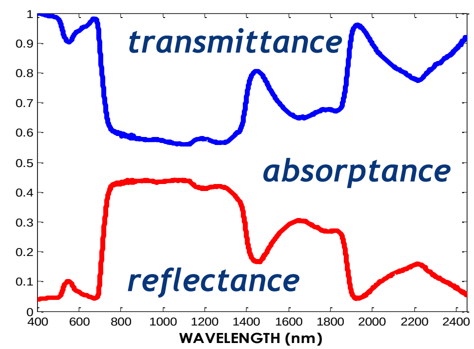
ALGORITHM STUDIES: PRELIMINARY RESULTS (1/3)

Statistical distribution (and co-distributions) of leaf chemistry (experimental)



Simulations of radiative transfer modeling

PROSPECT-5



Generation of a simulated dataset sharing chemical and structural properties with experimental data

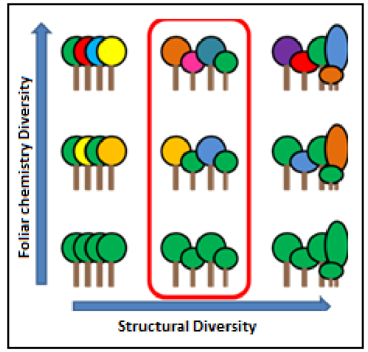
Database Leaf optical properties

Statistical model (spectral index, wavelets, ...) for the estimation of a chemical constituent (Feret et al., 201.5, Cheng et al. 2015.)

ALGORITHM STUDIES: PRELIMINARY RESULTS (2/3)

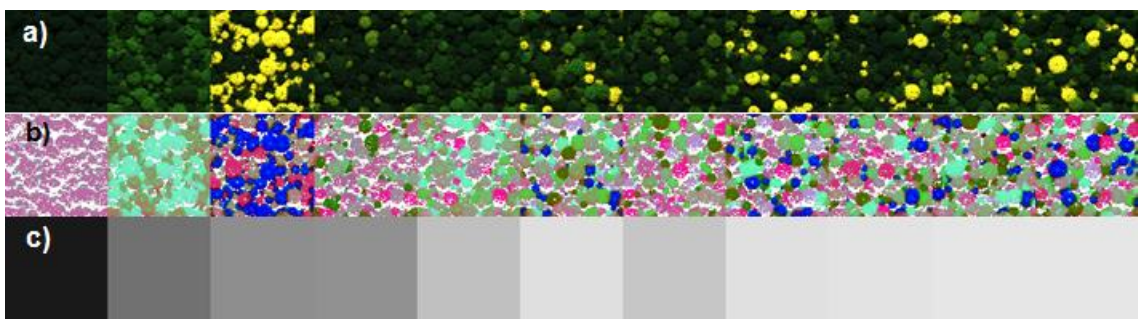
Signal sensitivity analysis in connection with the biological and structural diversity.

Sensitivity study combining a structural variation gradient vs. a diversity of leaf optical properties gradient. Red frame represents the different cases of simulations



The sensitivity study was constructed with a 3D model of <u>medium structural</u> complexity in which we introduced a gradient of 1 to 20 different among of <u>leaf optical properties</u> (PROSPECT model). DART, realized 11 hyperspectral simulated images.

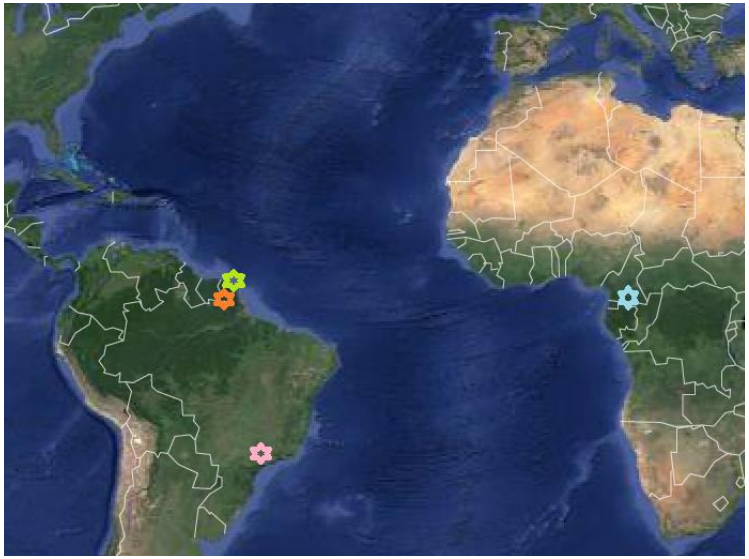
a) RGB representation of 11 hyperspectral DART simulations (with 1, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20 distinct leaf optical properties); b) composition of three selected components obtained fro PCA applied to DART simulations; c) biodiversity index based on the spectral variability (Féret & Asner 2014).

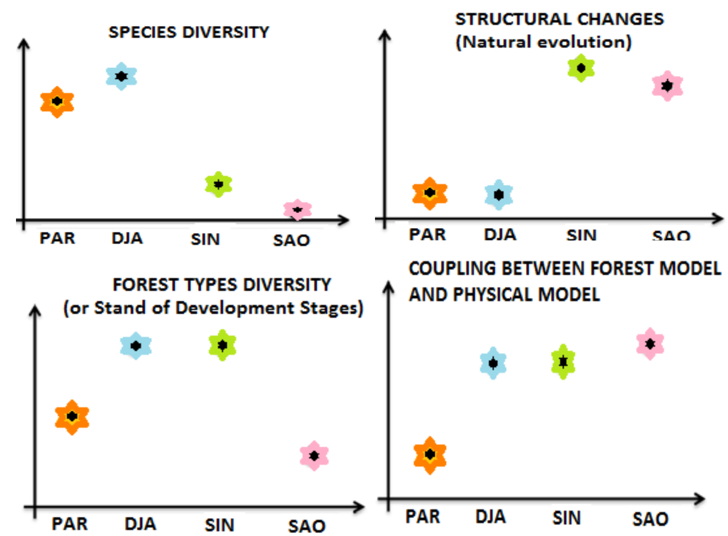


These qualitative results are promising and show a good correlation between biodiversity (represented in the simulations by a variety of leaf optical properties), and the biodiversity index derived from spectral information.

NEXT STEP FOR HYPERTROPIK : AIRBORNE ACQUISITIONS(1/2)

4 test-sites are selected as representing different stages of forest biodiversity





- **Dja test-site (Cameroon):** a dense and fragile rainforest characterized by a high diversity (species, architecture) and limited topographical variations**.**
- **Paracou / Nouragues test-sites (French Guiana):** a dense rainforest characterized by high species diversity, a structural variability TBD and a complex topography.
- **Sinnamary test-site (French Guiana):** mangrove consisting of only two dominant species, but, with a soil frequently flooded (tidal or rainy season), a high growth rate and fast changes.
- **São Paulo test-sites(Brazil):** eucalyptus plantations characterized by very low species diversity but with significant structural variability among clones and among growth stages

2015-2016 Paracou in situ and hyperspectral campaign (in preparation)

NEXT STEP FOR HYPERTROPIK : AIRBORNE ACQUISITIONS(2/2)

Data collection in French Guyana (campaign 2015)

Airborne campaign in preparation :
- Imaging spectroscopy VNIR+SWIR (HySpex)
- Scaner Lidar full wave form (Riegl-LMS-Q560)
- Camera RGB very high resolution

→ COPAS (Canopy Operating Permanent Access System) installed on the Nouragues site.

Field campaign synchronized with airborne campaign:
- Spectroscopic measurements of forests components : *soil, bark, branches, leaves from various species*
- Biochemical measurements (pigments, H20)
- T-LiDAR acquisitions in collaboration with other projects

Expectations:
- Construction of a 3D maquette with very high level of details for the validation of simulations
- Study intra- and inter-specific variability of leaf optical properties at the canopy scale, study the influence of such variations on the simulations
- Perform species community mapping across the study sites

SYNTHESIS & CONCLUSION

1- DART model has been improved and optimized for hyperspectral and Lidar simulations. The coregistered simulation of LiDAR and Hyperspectral signal is currently under development.

2- First results of hyperspectral simulations generated for **sensitivity studies** are very promising. More efforts need to be done to build sufficiently exhaustive sensitivity studies (definition of parameters + DART optimization). Next runs before the end of 2015**.**

3- An Airborne campaign combined with field data collection are scheduled for the end of 2015 and 2016 (TBC) in French Guyana (44km2)

4- The validation of DART simulations based on airborne and satellite images is scheduled for 2016 & 2017. Such simulations will strengthen **specifications for HYPXIM,** in particular for applications related to tropical biodiversity mapping.

Thanks for your attention